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AN AIR-BEARING WEIGHT OFFLOAD SYSTEM FOR GROUND TEST OF HEAVY LSS STRUCTURES

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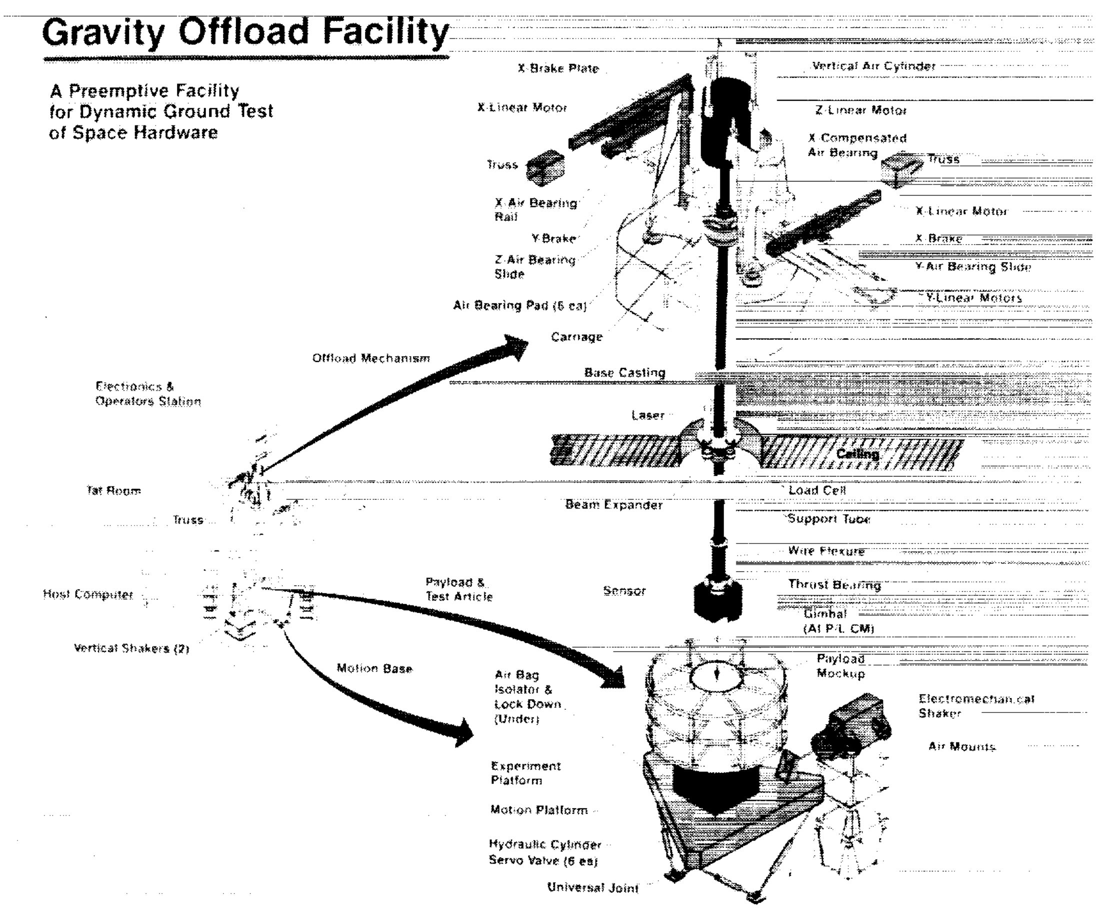
GRAVITY OFFLOAD OVERVIEW

The Gravity Offload Facility (GOF) is a Martin Marietta Capital funded laboratory facility intended for testing of heavy, compact payloads which require up to 6 degrees of freedom (DOF) motion. The primary use is to suspend a payload such as a sensor package or SBL* optical mirror above a delicate isolation or pointing mount which is the object of the test. The payload with its mass and inertia is allowed to move freely under the influence of the mount under test but must not burden it with its weight in the 1 g field.

Design and build of the facility occurred mainly over the calendar year 1987 at the MMAG Inertial Guidance Laboratory in Waterton (Denver), Colorado. The project was highly developmental in nature, due to the heavy weight, frictionless operation and 6 degree of freedom requirements. Several unique components were custom designed and fabricated by outside vendors, but the main design and development was accomplished in-house.

*space-based laser (SBL)



FACILITY CAPABILITY

The overhead air bearing assembly is designed for suspension of up to 10,000 LB. It allows frictionless 4 degree of freedom operation by using air bearings in the load path and guide rails. Two more degrees of angular freedom are accomplished at the payload CG by using either a two axis flexure mount for small angle applications or a spherical air bearing for large angles.

The payload is free to travel bounded by a cylinder 18 inches in diameter and 18 inches tall. Depending on which CG gimbal mount is used, angular travel can be up to 60 degrees in pitch and roll and is free to rotate about the vertical axis. Great care has been taken to minimize jitter or noise contamination of the payload from the suspension.

The motion base can provide 6 degree of freedom motion input for a 3000 LB dynamic (or a 10,000 LB static) load over a travel of 24 inches in all directions with a bandwidth up to a few Hz. Beyond this, individual electro-dynamic shakers can be attached to provide vibration inputs up to 2000 Hz at about the 100 LB force level. The system was intended to simulate the vibration and motion environment of the shuttle bay or an SBL aft body.

Suspended Load 6 DOF, Ultra Quiet

- Up to 10,000 lb
- 18 Inch Travel in X Y & Vertical
- Angular Travel Dependent on CG Gimbal
  Flexure: ±7°, ±15° about Vertical
  Spherical AB: ±30° Lateral, Free about Vertical

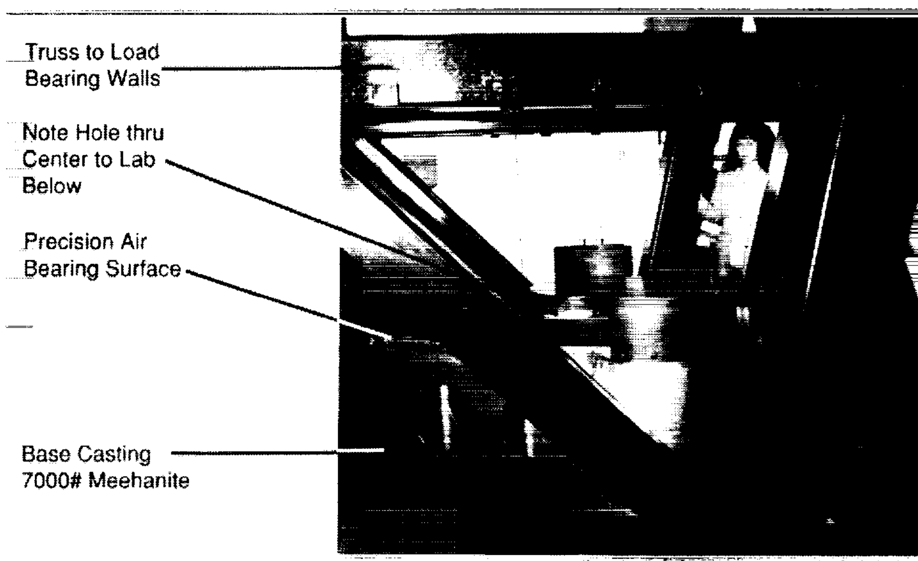
Motion Base 6 DOF

- Load 10,000 lb Static, 3,000 lb Dynamic
- Travel 24 Inch All Directions
- DC to 2000 Hz (Limited) Any Axis

TRUSS AND BASE CASTING

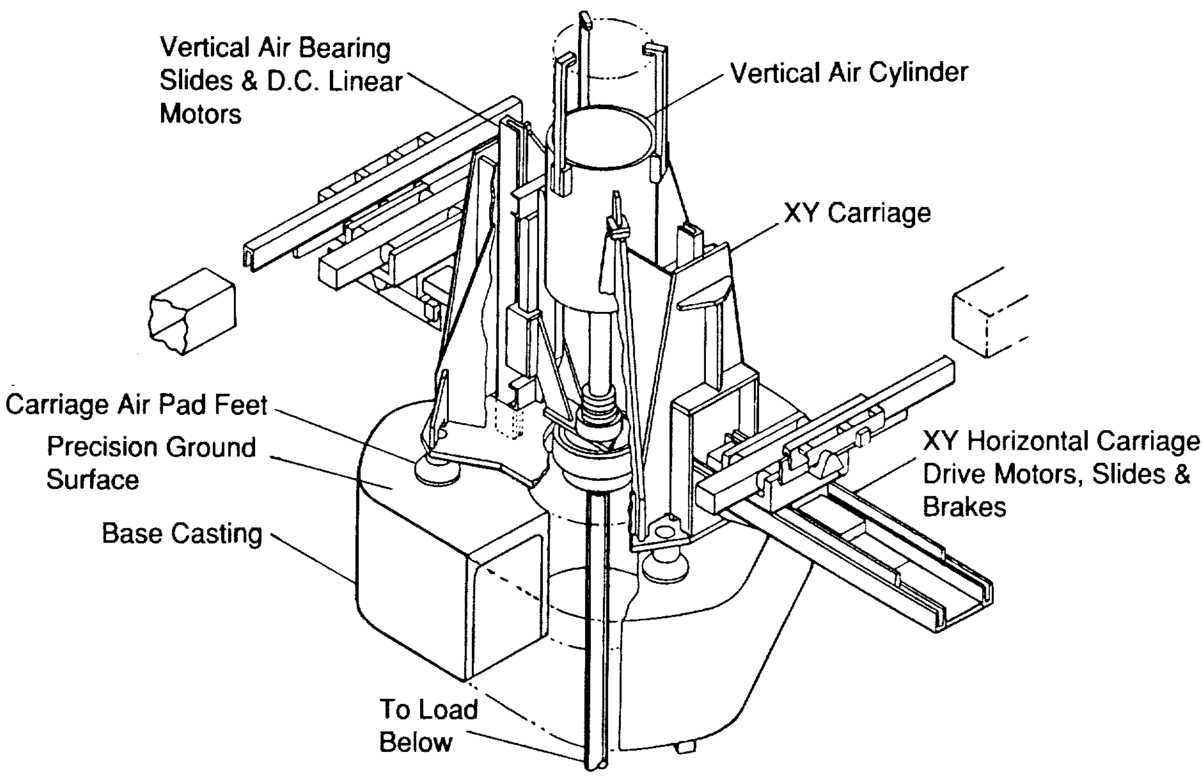
The truss which supports the base casting is sized to minimize angular tipping of the horizontal bearing face as the carriage moves from side to side. The vertical bounce natural frequency goal was to be above 50 hz. The truss is supported on load bearing walls (as opposed to a ceiling mount) to minimize vibration transmission. The casting mount is a 3 point suspension.

A large 7000 LB Meehanite one piece ribbed casting was chosen for backing the horizontal air bearing face. A weldment was considered unsuitable since it would probably not hold tight tolerances after grinding. A granite slab was found unsuitable due to the weight. A great deal of trouble was encountered trying to obtain a high quality air bearing surface due to the large size involved, and the requirements of better than a 10 microinch surface finish and a planarity of better than 50 microinches.



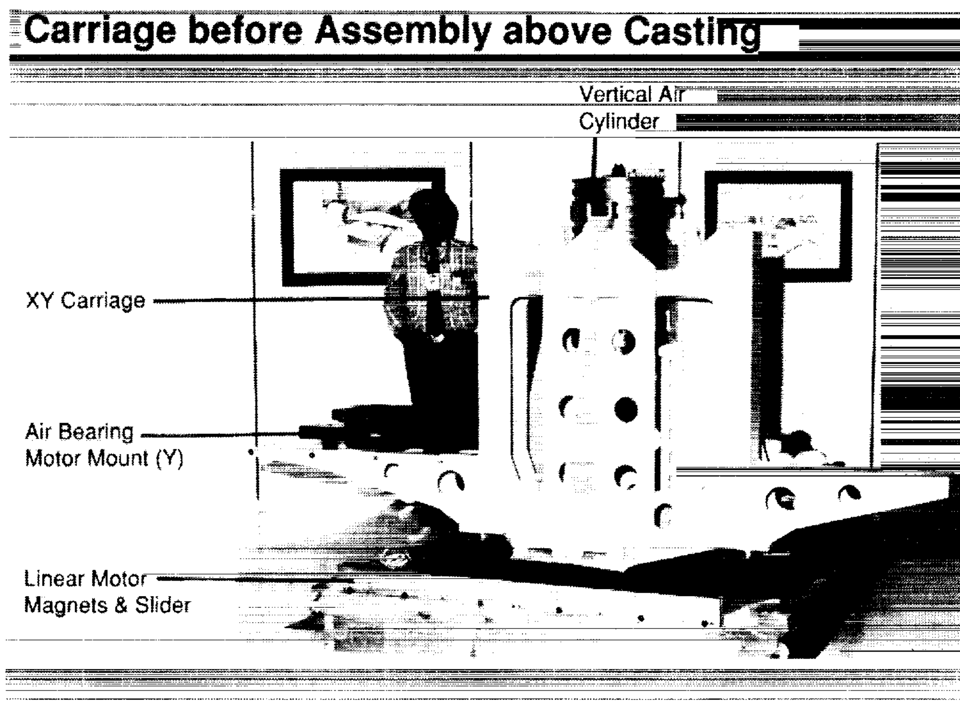
CARRIAGE ASSEMBLY

The carriage provides the X Y lateral freedom thrust bearing for the overhead suspension. It rides on six self aligning air bearing feet which travel over the base casting precision surface. It was sized for the 10,000 LB maximum load, and carries the X Y linear motors, slides and sensors. The vertical lift cylinder also rides in the center and provides the vertical degree of freedom. An air bearing gimbal is used to allow angular freedom of the piston rod about the vertical axis. The load path connects directly from the payload up the pipe to the piston. The vertical motors and sensors are connected to the vertical pipe through the gimbal bearing but they ride on their own air slides.



CARRIAGE WELDMENT

The X Y carriage is shown here before assembly. It is constructed from a weldment on which precision points were machined as a final step. One of the six linear motors is shown which provides control of the 3 translational degrees of freedom. These unique motors provide a direct drive frictionless control force without cogging or ripple. Two motors per axis are mounted each on their own air slides with a linear position sensor. Each motor may exert up to 150 LB which yields 300 LB per axis.



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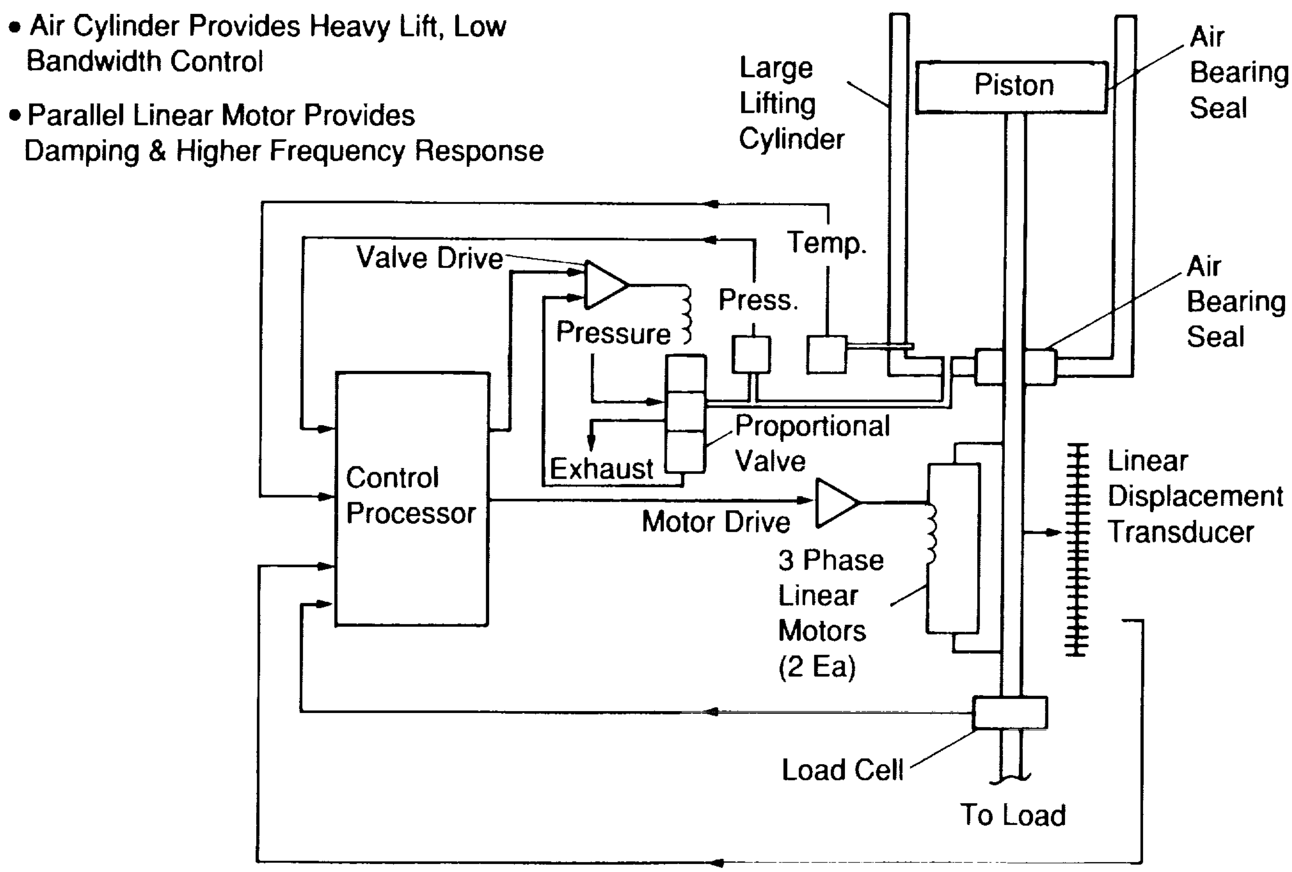
VERTICAL LIFT AXIS CONTROL

The vertical degree of freedom proved to be the most difficult to design. The large air cylinder is used to support the overall payload weight but provides only low frequency support. Two parallel linear motors are used to provide control and damping. A large diameter proportional valve is used to control the cylinder air pressure. Pressure, temperature, load and position are all fed back to control the cylinder. The valve position has its own control loop with sensor and actuator.

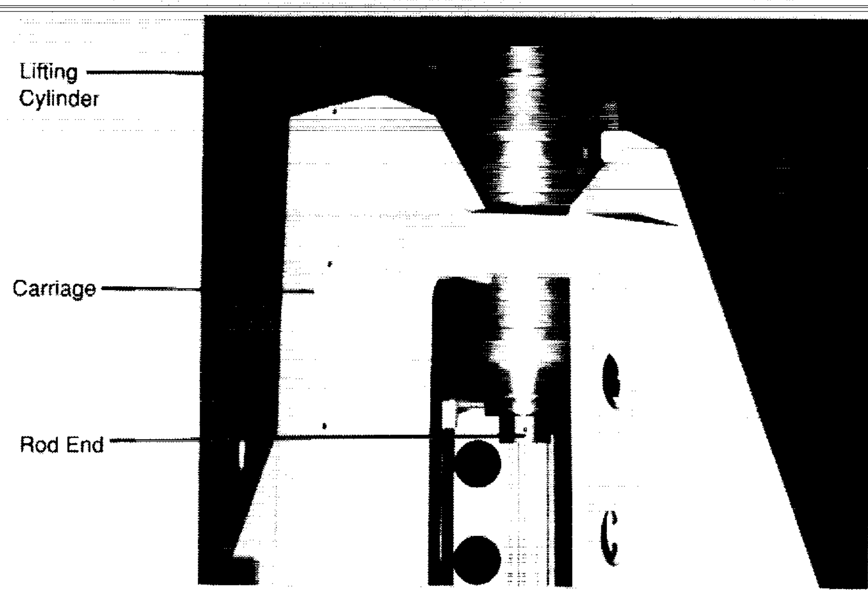
During the design phase extensive use was made of a time domain simulation of the valve, cylinder and gas dynamics. Non-linear compensation was designed to compensate for the wide range of loads and cylinder volumes using this tool. The blend of linear motor versus valve control influence was also defined using this simulation.



LIFTING CYLINDER

The vertical lifting cylinder is shown here prior to assembly. To maintain frictionless operation, the cylinder rod seal and piston had to be designed using air bearings. Team Corp. of El Monte, Ca. took on the job of developing and building this cylinder. The combination of large bore and deep stroke presented a great deal of trouble in fabrication due to the extremely tight tolerances needed for the air bearing surfaces over the full travel. The tradeoff was between frictionless operation and minimal air consumption. The air gap had to be held to less than 400 microinches over the travel and range of pressures.

Vertical Air Cylinder, Mounted in Carriage



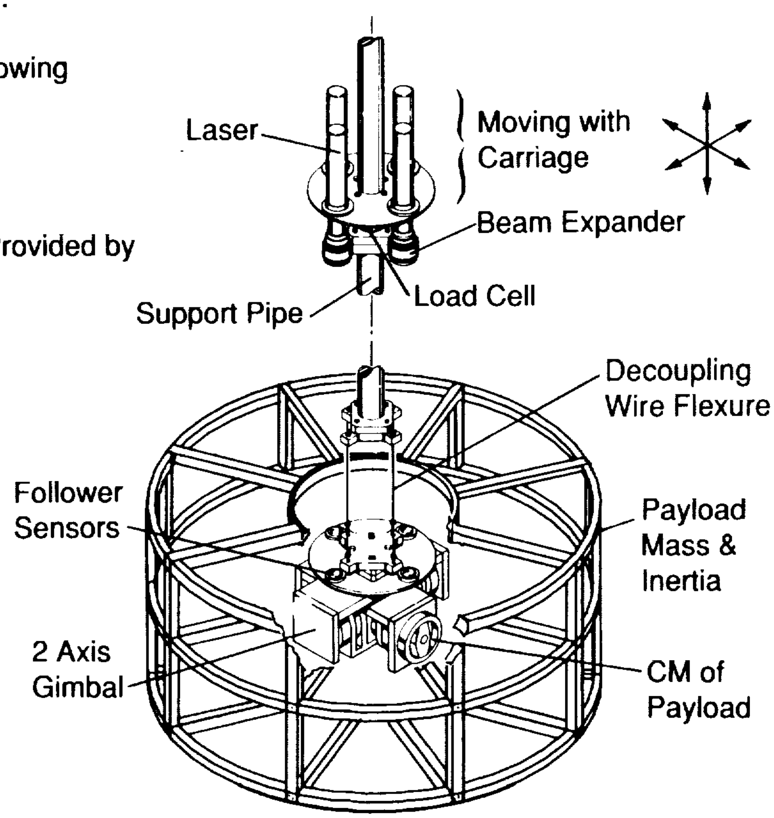
PAYLOAD FOLLOWER AND PAYLOAD GIMBAL

To minimize the effects of the carriage mass, the X, Y and θ_Z axes use a servo to follow the payload motion. Lasers with converging optics are mounted beneath the carriage. Their light spots impinge on sensors mounted just above the payload. Any error is sensed and the linear motors re-align the X Y carriage and the vertical rotation.

The payload angular degree of freedom in pitch and roll is accomplished using a two axis gimbal located at the payload center of gravity. For small angle applications flex pivots are used. For larger angles a spherical air bearing may be used.

Dynamic decoupling of the payload from the overhead suspension is accomplished using a four wire flexure located above the payload gimbal point. This decouples the X Y and θ_Z axes.

- Carriage Follows Payload Closely:
  - Vertically Following Load Cell
  - Horizontally & Rotationally Following Optical Sensors
- Gimbal Pivots about Payload CM
- Small Motion Vibration Isolation Provided by In-Line Wire Flexure

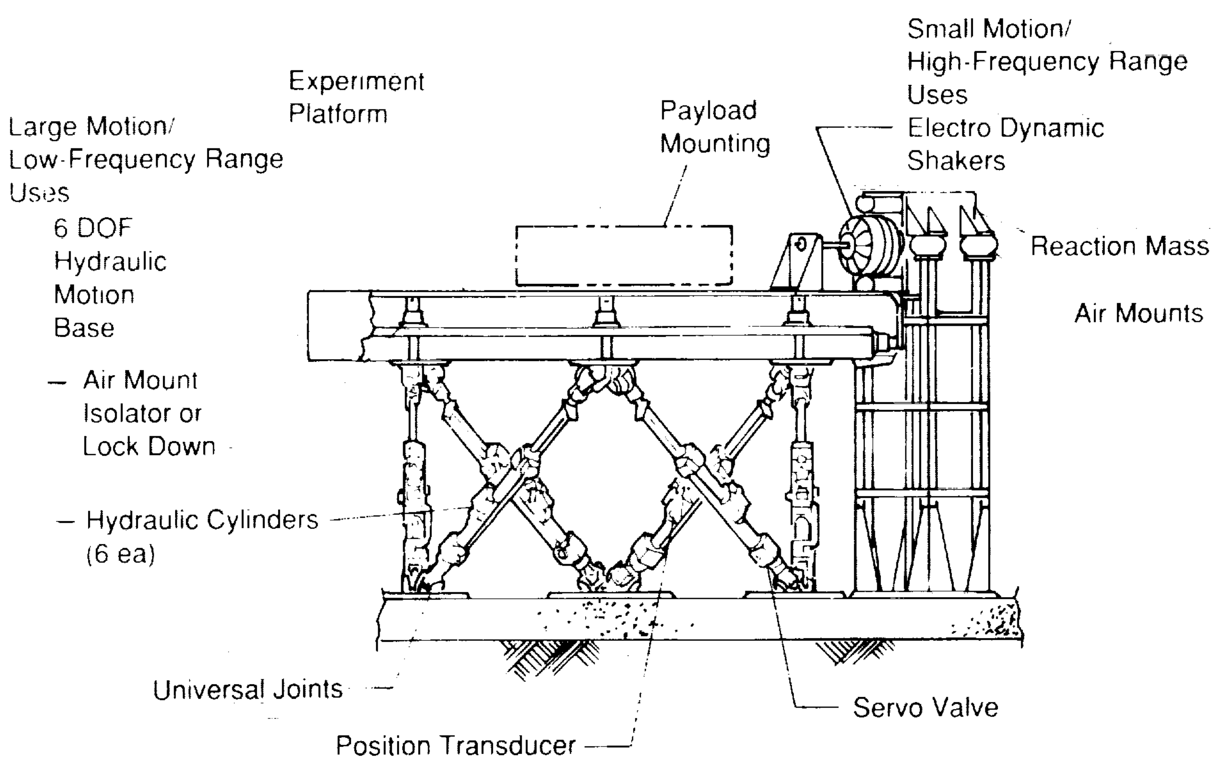


MOTION BASE LAYOUT

A realistic vibration disturbance environment which simulates that experienced in the shuttle bay or that found on the aft body of an SBL is the goal. Low frequency, large, 6 degree of freedom motion is generated using the hydraulic hexapod. High frequency, small motion inputs are obtained by judicious connection of electro dynamic shakers.

The hydraulic hexapod chosen is a unit routinely used for aircraft simulator crew training. When only large motion is required the experiment platform is clamped to the motion base. When only small-motion high frequency is required, the experiment based is isolated on air mounts and fixed at some orientation, then the electro dynamic shakers are attached. For combined motion, the shakers may ride on the motion base and shake the experiment while the hexapod goes through its maneuvers.

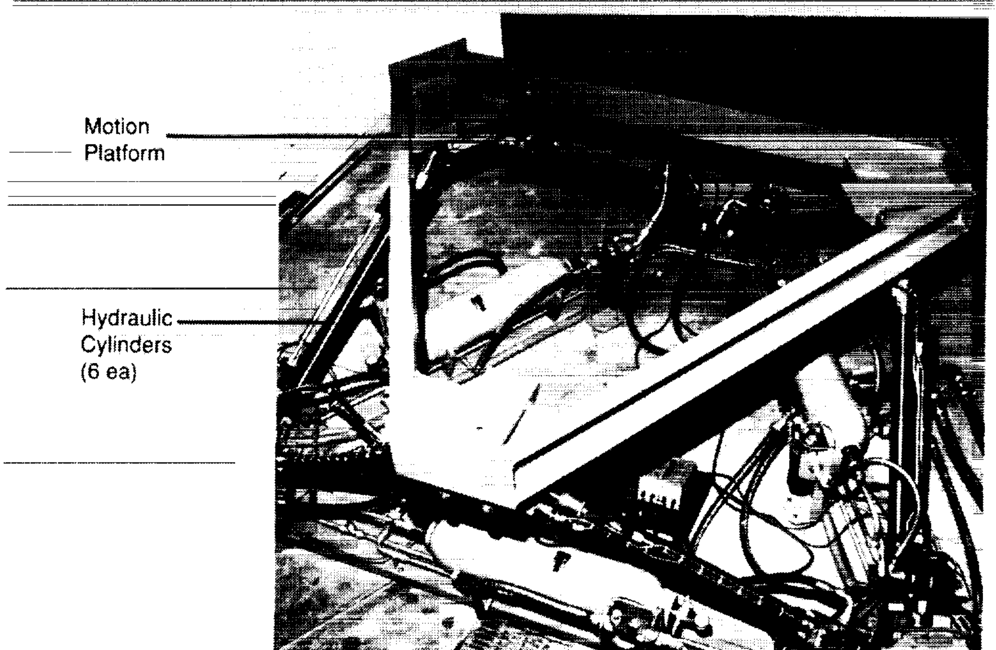
Disturbance Input



MOTION BASE

The 6 degree of freedom hydraulic motion base is built by Flight Safety International of Tulsa, Ok. Six skewed hydraulic cylinders are arranged in a hexapod connected by special U joints. The cylinders have hydrostatic bearings and seals to minimize friction. The valves are precision proportional Moog valves similar to those used on launch vehicles. Very fine control and minimal jitter is achieved. The motion base slew rate is 23 inches per second in any direction and the small signal bandwidth is in the range of 5 Hz.

6 Degree of Freedom Motion Base* Hydraulics



* Motion Base from Flight Safety International Corp., Tulsa, OK

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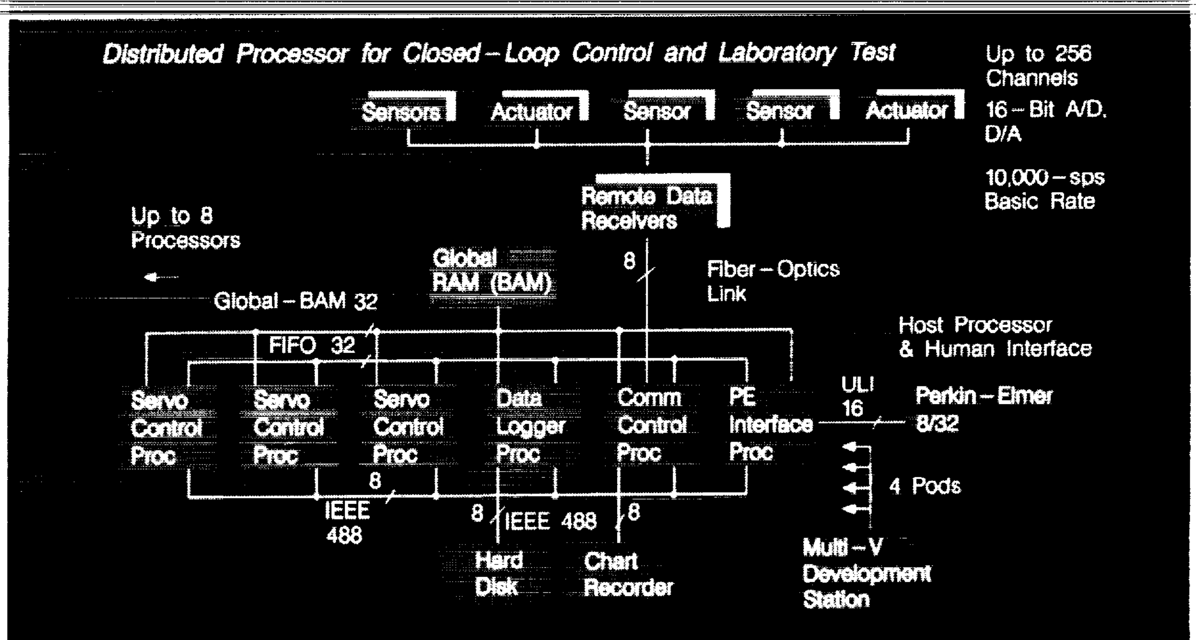
CONTROL PROCESSOR

The control processor is required to simultaneously perform real time closed loop control of the 6 suspension axes, collect data from the experiment sensors, and must also be modular to allow for future expansion and the modifications usually required by each new experiment. An architecture was chosen which is ideally suited to this task. Since a great deal of the operation has to do with distribution of data, one whole processor and special interface hardware were designed for this task. Experiment data collection was assigned to a second processor and the human interface to a third. This leaves up to 5 more processors available for process control. The bus structure was designed to eliminate data transfer bottle necks. Memory has been allocated such that each processor has its own local memory for program code plus some local dynamic use. Also, a global memory is available for common usage between processors. As far as the control function is concerned, input and output is automatic at the basic RTI rate of 10 KSPS, thus data transfer to the hardware does not slow the computation algorithm. Each processor with its co-processor can perform approximately 400K FLOP.

Custom Distributed Processor for Closed-Loop Control and Laboratory Test



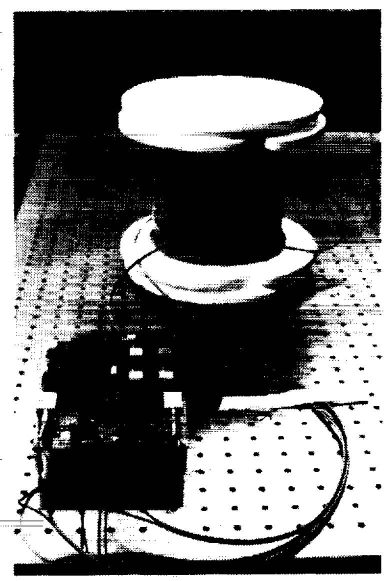
HARDWARE & EXPERIMENT DATA LINK

The combination of multiple channel, high data rate, high resolution, and low noise requirements drove the design to fiber optic data links between the hardware and the processor. Hardware A/D and D/A interfaces are close to the experiment. Cross talk and noise usually associated with long lines are eliminated and mechanical vibration transmission due to heavy cable drops is minimized due to the fiber's small size.

Three prototype builds were required for the electronics which interfaces the computers to the fiber optics. Layout proved to be extremely critical due to the high frequencies involved.

Fiber Optic Data Link between Experiment and Processor

- Minimize Mechanical Noise Transmission
- Eliminate Cross Talk & Noise between Motor Drives & Sensor Channels
- Multiplex Many Channels



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FACILITY USES

The GOF facility was originally designed to support testing of the Space Active Vibration Isolation (SAVI), hardware and also provide a hardware development capability leading to the Zenith Star Laboratory test. Other interesting uses for the test facility are: close rendezvous and dock between two bodies, manipulator studies and fine pointing experiments. The common characteristic of the applications seems to be that one body is dynamically orientable in 6 DOF, and the other is free to move in a quiet environment, again in 6 DOF.

1. Space Active and Passive Vibration Isolators
2. Gimbal Mounts
3. Fine Pointing Experiments
4. Rendezvous and Dock
5. Retargeting Experiments